KINEMATIC STUDY IN THE AREA OF THE QUATERNARY OBLIQUE-SLIP *EL TIGRE FAULT*, WESTERN PRECORDILLERA, ARGENTINA, ON THE BASIS OF PALEOMAGNETISM AND ANISOTROPY OF MAGNETIC SUSCEPTIBILITY

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Abstract

The *El Tigre* fault, in the Western Precordillera of the San Juan province, Argentina, is a major Quaternary strike-slip fault that outstands for its 120 km of length, good grade of exposure and geomorphic markers of horizontal displacement, as well as for a vertical component evidenced by a remarkable high east-facing scarp with a steep slop in its central part. Despite this, there have been controversies about the geometrical and kinematic characteristics of the fault and, in general, these have not been discussed in depth. We present the use of the study of paleomagnetism and anisotropy of magnetic susceptibility (ASM) on sediments exposed on or near the fault trace, with the aim of better constraining the kinematics of this major fault. Paleomagnetic results along the fault show the presence of sections with very different amount of tectonic rotations and the presence of both clockwise and counterclockwise rotations. However, the magnitude of rotations are apparently related to the age of the sediments involved and the overall pattern can be simply modeled through a system of domino-rigid block rotations with significant drag along the main and secondary faults. AMS results showed the dominance of tectonic fabrics in the Late Tertiary and Quaternary yet unconsolidated sediments and permitted to detect a possible a regional change in the tectonic shortening direction between the Middle Pleistocene and the Upper Pleistocene, from WSE-ENE to W-E.

Resumen

La falla El Tigre, en la Precordillera Occidental de la provincia de San Juan, es una falla cuaternaria de deslizamiento de rumbo dextral que se destaca por sus 120 km de longitud, buen grado de exposición y marcadores geomórficos de desplazamiento horizontal y, asimismo, por una componente vertical evidenciada por una elevada escarpa con cara al este y pendiente empinada en su sector central. Sin embargo, se han presentado controversias respecto de las características geométricas y geomórficas de la falla que, en general, no han sido discutidas en profundidad. Presentamos aquí la utilización de estudios paleomagnéticos y de anisotropía de susceptibilidad magnética (ASM) en sedimentos expuestos sobre o cerca de la traza de la falla, con el objetivo de caracterizar la evolución cinemática de la misma. Los resultados paleomagnéticos a lo largo de la misma muestran la presencia de secciones con valores muy diferentes de rotaciones tectónicas, tanto horarias como antihorarias. Sin embargo, las magnitudes de estas rotaciones están aparentemente relacionadas con la edad de los sedimentos involucrados y el patrón

general puede ser modelado en forma simple por un sistema de rotación en bloques rígidos en dominó con un arrastre significativo a lo largo de la falla principal y de fallas secundarias. Los resultados de ASM mostraron un dominio de fábricas tectónicas en el Terciario Tardío y en sedimentos aún no consolidados del Cuaternario y permitieron detectar un posible cambio regional en la direcciones de acortamiento tectónico entre el Pleistoceno Medio y el Pleistoceno Superior, desde el WSE-ENE al W-E.

Introduction

El Tigre is a dextral strike-slip Quaternary fault (*Figure 1 a*) of 120 km of length (INPRES, 1982; Bastías et al., 1984; Siame et al., 1997a, 1997b; Cortés et al., 1999) in the central Western Precordillera of San Juan, Argentina, situated in a major active seismic area (INPRES, 1977). Because of this, the study of the geometry and kinematics of this fault is significant to better estimate the seismic risk in the region. Even though its significance, the fault has not been systematically studied through geophysical methods.

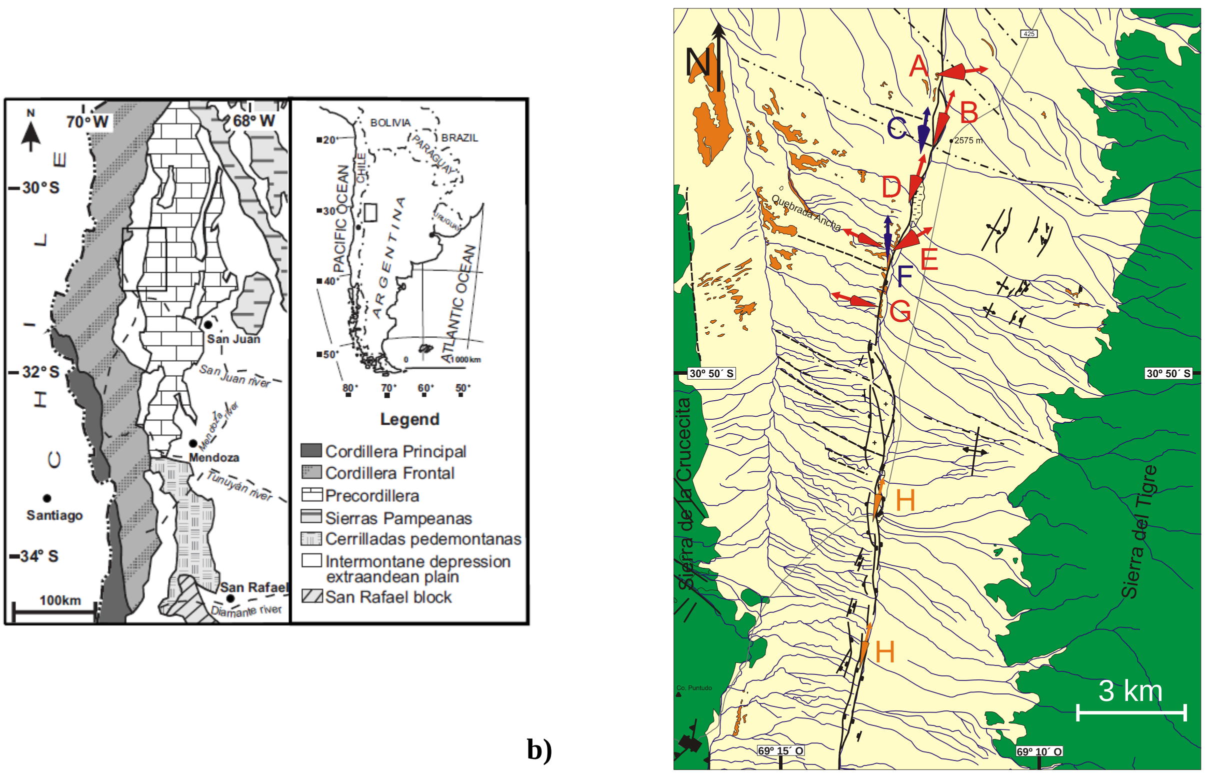

Figure 1. a) Location of the *El Tigre* fault within the Argentine Western Precordillera, San Juan province. **b)** Mean rotations around vertical axis determined at eight different sample zones in the central section of the *El Tigre* fault. Red arrows represent Middle Miocene-Lower Pliocene sediments (zones A, B, D, E, G), orange arrows Middle Pleistocene alluvial deposits (zone H), and blue arrows Upper Pleistocene deposits (zones C, F). Cones represent 95% confidence limits. The mapped units represent: present fluvial courses (blue), undifferentiated aggradation levels of alluvial and fluvial sediments and bog sediments (yellow), the Middle Miocene-Lower Pliocene Las Flores Formation (dark orange) and undifferentiated units of the Pre-Cenozoic substratum (green).

The Central Segment (Siame et al., 1997b) is characterized by a significant east–dipping scarp (18º-24º, 85 m of maximum height) along which late Miocene sediments and fluvial deposits of Middle Pleistocene age have been exposed due to tectonic uplift, indicating significant vertical displacements along the fault zone too.

Several authors have shown that detection of rigid block rotations with paleomagnetism (Itoh et al., 2003; Kimura et al., 2004; Mattei et al., 2004; Itoh et al., 2008) can help to elucidate the kinematic history of a fault system, by determining sense and amount of local crustal block rotations along the fault, their extension and age. Moreover, the magnetic fabric of a rock, that can be defined by the anisotropy of magnetic susceptibility (AMS), has become a valuable tool in many fields, such as the tectonic deformation of rocks. Studies in unconsolidated to scarcely consolidated sediments have been used to define directions of paleowinds and other environmental aspects, but its use in sediments affected by different degrees of neotectonic deformation, though not evident macroscopically, is recent and still scarce (Mattei et al., 1999; Sagnotti et al., 1999; Larrasoaña, 2011). So, integration of both methods could provide new contributions to understand the kinematic behavior of the fault zone.

In the present work we briefly describe the results of a paleomagnetic and AMS study carried out on generally poorly to non-consolidated Middle Miocene-Lower Pliocene sediments (24 sites), Middle Pleistocene (2 sites) and Upper Pleistocene alluvial deposits (5 sites), exposed along the Central Segment of the *El Tigre* fault and their kinematics implications.

Methodology

Sampling of sediments along the Central Segment of the *El Tigre* fault was carried out at 31 sites (8 to 20 samples at each). The clastic sediments sampled were of varied granulometry and with no macroscopic internal deformation. Samples were collected as plastic cylinders 22 mm high and 26 mm in diameter, as drilled cores or as hand samples. Eight sampling zones (A to H, see *Figure 1b*) were defined, which contain sampling sites that are in general separated by no more than 1.15 km apart. Five zones (A, B, D, E, G, in red in *Figure 1b*) are constituted by Middle Miocene-Lower Pliocene sediments, two zones (C, F, in blue in *Figure 1b*) by Upper Pleistocene deposits and one zone (H, in orange in *Figure 1b*) by Middle Pleistocene alluvial deposits. Stepwise AF demagnetization in 16 steps up to 120-mT or thermal demagnetization in 11 steps up to 560º was applied to the samples. Stepwise demagnetization was performed on 442 samples (31 sites). A 2G Enterprises (550R) cryogenic magnetometer with SQUID-DC sensors was used to measure the magnetization of these samples. Directions of the components of magnetization were obtained through principal component analysis. The mean direction of the characteristic component for each zone was calculated through Fisher´s statistics and then the Beck's direction-space approach was used to compute the values of rotation around vertical axes. Present day GAD direction at the study area was used as reference for computing rotation values. These results for each zone are shown by arrows in *Figure 1b*, with cones representing 95% confidence limits.

The anisotropy of magnetic susceptibility of 273 samples (19 sites) was determined with an AGICO MFK1B susceptibility-meter by means of the fifteen-position protocol (Tauxe, 2003). From these measurements the directions of the semi-axes of the best fitting ellipsoid of AMS for the sites, with the respective confidence angles, were calculated applying Jelinek´s statistics (1978), in addition to other standard parameters such as Pj (corrected anisotropy degree) and T (shape parameter).

Results and interpretation

Positive paleomagnetic results were obtained in 21 sites permitting to identify zones along the fault with different kinematic behaviors. Rotations with variable magnitudes (from around 20° to 84°) were found in the Middle Miocene-Lower Pliocene deposits, in general of clockwise character but, in zones limited by important secondary oblique faults, large counterclockwise rotations were also detected. The Middle Pleistocene deposits presented small (13º approximately) clockwise rotation, whilst no significant rotation was found in the Upper Pleistocene sediments. These results were interpreted in terms of a block rotation domino-pattern with significant drag along the main and secondary faults.

The mean susceptibility of the samples varied from 4.10^{-5} to 1.10^{-3} SI and the corrected anisotropy degree was low for all the sites, from 1.004 to 1.059. The shape of the fitted ellipsoids of anisotropy resulted in: 14 oblate, 4 prolate and 1 triaxial. Magnetic fabric with different degrees of tectonic overprint was observed. These varied from a typical depositional fabric to a typical tectonic fabric. This is particularly interesting since very little to no macroscopic deformation can be observed in the study lithologies. Thus, a magnetic criptofabric of tectonic origin was found in 7 out of 12 Miocene, 1 out of 2 Middle Pleistocene and 4 out of 5 Upper Pleistocene sites. The directions of the k1 and k2 / k3 axes are interpreted as those of maximum extension and compression directions, respectively, during acquisition of the tectonic fabric. Directions of AMS principal axes were "unrotated" by the paleomagnetically determined rotations, yielding to a much better grouping of site-mean k1 and k3 directions. These AMS data suggest a significant change from WSW-ENE to W-E in the tectonic shortening direction along the central section of the El Tigre fault, which may have occurred by the end of the Middle Pleistocene. This is consistent with a possible change in the kinematics of this section of the fault from a main transcurrent regime to a more transpressive/transtensive one in the Upper Pleistocene.

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